EARLY LIFE NUTRITION AND MANAGEMENT IMPACTS LONG-TERM PRODUCTIVITY OF CALVES

M. E. Van Amburgh, F. Soberon, J. Karzses, and R. W. Everett
Department of Animal Science
Cornell University, Ithaca, NY

INTRODUCTION

Discussing the topic of calves and calf management over the last 40 years traditionally involved dry cow management, colostrum, scours, rumen development and early weaning. In the last ten years, the concept of "intensified feeding or accelerated growth" has become a focus of discussion and during that time the concept has been applied to research programs and on farm in various ways. Much of this discussion involves differences in perspectives about how to best manage the nutrition and nutrient intake of the pre-weaned calf. There are teleological arguments for providing a greater supply of nutrients from milk or milk replacer, e.g. what would the dam provide, and there are also arguments for improving the welfare status of the animals by following the same concept (Jasper and Weary, 2002; de Paula Vieira et al., 2008). At the 15th American Dairy Science Association Discover Conference on Calves (Roanoke, VA) the overwhelming consensus of the participants was that we need to feed calves for a specific rate of daily gain, much higher than the traditional industry standards, and that is a significant change in industry perspective.

EARLY DEVELOPMENT AND PRODUCTIVITY

Colostrum Status

To maximize calf survival and growth, plasma immunoglobulin (Ig) status and thus colostrum management is of utmost importance. This is obviously not a new concept and there are hundreds of papers describing the management and biology surrounding colostrum quality, yield and Ig absorption by the calf although some recent research in colostrum handling and management suggest we can still make improvements (Godden, 2008). A proper discussion of colostrum includes factors other than Ig and should include the myriad of other factors in colostrum that have shown to be beneficial to the calf. Factors like insulin, insulin l-like growth factor-I (IGF-I), maternal leukocytes, oligosaccharides, growth hormone, relaxin, leptin, short chain fatty acids and many other useful compounds found in colostrum and that are most likely very important in the response of the calf to ingestion of the secretion. Minimizing the bacterial load of colostrum is probably one of the major management concerns with many farms and is usually a factor not considered or analyzed for. Data demonstrate that the presence of bacteria in the gut prior to colostrum ingestion or in the colostrum reduces the uptake of Ig, thus increasing the incidence of failure of passive transfer (James et al. 1981, Godden, 2008). Thus excellent udder health and proper post-harvest colostrum handling is as important, or even more important than vaccination programs to prevent diseases.

Of interest for this paper are the studies that have described decreased growth rate and increased morbidity of calves with low serum immunoglobulin status (Nocek, et al., 1984; Robison et al., 1988) and some have even indicated that milk yield during first lactation can be affected (DeNise et al., 1989). Robinson et al. (1988) indicated that calves with higher Ig status were able to inactivate pathogens prior to mounting a full immune response which allows them to maintain energy and nutrient utilization for growth, whereas calves with low Ig status must mount an immune response which causes nutrients to be diverted to defense mechanisms. How severe is this difference or for how long does it persist? The data of DeNise et al., (1989) demonstrated that for each unit of serum IgG concentration, measured at 24 to 48 hrs after colostrum feeding, above 12 mg/mL, there was an 18.7 pounds increase in mature equivalent milk. The implication is that calves with lower IgG concentration in serum were more susceptible to immune challenges which impacted long term performance. As with all longitudinal and epidemiological studies there are inconsistencies. Donovan et al. (1998) found indirect effects of colostrum status on growth and performance of calves, but concluded it was caused by increased morbidity and not a direct effect. The calculations of growth and feed efficiency should in many cases include the calves that were lost to study, thus providing a more applicable value.

Another study comparing two different allowances of colostrum suggested that the impact of serum Ig concentrations was not nearly as great as the DeNise et al. (1989) study, but did affect milk yield and survival through the second lactation (Faber et al., 2005). Brown Swiss calves were provided either 2 or 4 L of colostrum just after birth with some additional meals over a 4 day period. The calves were monitored after calving for two lactations. At the end of the second lactation three major observations were made. First, there was a 30% increase in pre-pubertal growth rates based on colostrum feeding level, under identical feeding conditions. Second, there was a 16% increase in survival to the end of the second lactation of calves fed the four liters of colostrum. Finally, the surviving calves fed the 4 L of colostrum produced 2,263 lbs more milk by the end of the second lactation. Although somewhat subtle, these differences suggest that early life colostrum status was important for long-term productivity. If part of the mechanism is related to maintaining nutrient partitioning towards growth via high immunoglobulin status, then the concept of nutrient status should also demonstrate responses beyond the Ig status of the calf. This difference in growth rate has been observed in studies comparing colostrum with colostrum replacement. Calves fed serum based colostrum replacer had nearly identical plasma IgG concentrations, but grew at a rate 30% less than the colostrum fed calves (Mowrey, 2001) and consumed the same amount of milk replacer.

The breakpoint for failure of passive transfer used in the literature has been between 10 to 12 mg/mL of IgG in plasma, however those values might be a partial proxy for other absorbed factors that impact productivity. A study recently conducted by our group compared the pre and post-weaning growth performance of calves that received either 2 or 4 L of colostrum in their first feeding. All calves had plasma IgG concentrations above 12 mg/mL adjusted for hematocrit (27 vs. 15 mg/mL for calves fed 4 or 2 L of colostrum respectively). Calves that consumed 4L of colostrum at the first feeding had an ADG 0.28 lb higher than calves receiving 2 L of colostrum over the first 80 d of life (Soberon and Van Amburgh, 2011a). The benefits of achieving IgG concentrations beyond the cutoff point of 10 mg/dL were confirmed by Furman-Fratczak et al. (2011). In their study, calves were classified according to IgG status at 30 h of life into 4 groups (<5, 5-10, 10-15 and >15 mg/dL). The group with higher plasma IgG concentrations avoided respiratory infections and had lower incidence of diarrhea cases. In this study calves with IgG concentrations above 10 mg/dL had greater rates of gain and reached breeding weights earlier than calves with failure of passive transfer. We believe these growth effects are due to factors in colostrum other than Ig's such as insulin, IGF-I, leptin and others.

Nutrient status and long-term productivity

There are several studies in various animal species that demonstrate early life nutrient status has long-term developmental effects. For a more extensive discussion of this topic, a recent review of these concepts was conducted by Drackley (2005). Aside from the improvement in potential immune competency, there appear to be other factors that are impacted by early life nutrient status.

There are several published studies and studies in progress that have both directly and indirectly allowed us to evaluate milk yield from cattle that were allowed more nutrients up to eight weeks of age. The earliest of these studies investigated either the effect of suckling versus controlled intakes or ad-libitum feeding of calves from birth to 42 or 56 days of life (Foldager and Krohn, 1994; Bar-Peled et al, 1997; Foldager et al, 1997). In each of these studies, increased nutrient intake prior to 56 days of life resulted in increased milk yield during the first lactation that ranged from 1,000 to 3,000 additional pounds compared to more restricted fed calves during the same period (Table 1). Although they are suckling studies, milk is most likely not the factor of interest, but nutrient intake in general and this is demonstrated in the more recent data.

In the study conducted at Miner Institute, Ballard et al. (2005), reported that at 200 days in milk, the calves fed milk replacer at approximately twice normal feeding rates produced 1,543 pounds more milk than calves that received one pound of milk replacer powder per day. Calving age in that study was not affected by treatment. Overall, averaging the studies, there is a 1,500 pound response to increasing nutrient intake prior to weaning on first lactation milk yield. The significant observation is that the effect of intake level needs to be accomplished through liquid feed intake.

The responses in the studies of Shama et al. (2005) and Moallem et al. (2010) are significant, specifically because they suggest that milk replacer quality is important to achieve the milk response, as is protein status of the animal post weaning. In that study, the calves were fed a 23% CP, 12% fat milk replacer containing some soy protein or whole milk. Further, post-weaning the calves were fed similarly until 150 days of gain, and the diets were protein deficient (~13.5% CP). Starting at 150 days calves from both pre-weaning treatments were supplemented with 2% fish meal from 150 to 300 days of life. The calves allowed to consume the whole milk (ad libitum for 60 minutes) and supplemented with the additional protein produced approximately 1,700 pounds more milk in the first lactation indicating that the early life response could be muted by inadequate protein intake post-weaning.

Finally the data of Drackley et al. (2007) again demonstrate a positive response of early life nutrition on first lactation milk yield. In this study, calves were fed either a conventional milk replacer (22:20; i.e. 22% protein, 20% fat) at 1.25% of the body weight (BW) or a 28:20 milk replacer fed at 2% of the BW for week one of treatment and then 2.5% of the BW from week 2 to 5 and then systematically weaned by dropping the milk replacer intake to 1.25% of the BW for 6 days and then no milk replacer. All calves were weaned by 7 weeks of age and after weaning all calves were managed as a single group and bred according to observed heats. The heifers calved between 24 and 26 months of age with no significant difference among treatments. Calving BW were also not different and averaged 1,278 lb. Milk yield on average was 1,841 pounds greater for calves fed the higher level of milk replacer prior to weaning.

Table 1. Milk production differences among treatments where calves were allowed to consume approximately 50% more nutrients than the standard feeding rate prior to weaning from liquid feed.

Study	Milk yield, lb
Foldager and Krohn, 1994	3,092
Bar-Peled et al., 1997	998
Foldager et al., 1997	1,143
Ballard et al., 2005 (@ 200 DIM)	1,543
Shamay et al., 2005 (post-weaning protein)	2,162
Rincker et al., 2011 (proj. 305@ 150 DIM)	917
Drackley et al., 2007	1,841
Raeth-Knight et al., 2009	1,800
Morrison et al., 2009 (no diff. calf growth)	0
Moallem et al., 2010	1,600
Soberon et al., 2011	1,700

The Cornell University Dairy Herd started feeding for greater pre-weaning BW gains many years ago and we have over 1,200 weaning weights and 3+ lactations with which to make evaluations outside of our ongoing study. What makes our approach to this unique is the application of a Test Day Model (TDM) (Everett and Schmitz. 1994; Van Amburgh et al., 1997) for the analyses of the data. This approach allows us to statistically control for factors not associated with the variables of interest and is the same approach that has been used to conduct sire summaries and daughter evaluations and develop heritabilities for genetic traits. Thus, the outcome is mathematically more robust and allows us to look within a herd over time with less bias and to look at herd responses independent of formal treatments. The resulting residuals are standardized which makes them additive over the life of the animal and they can be calculated for individual test days or over the lactation. The power of this type of analyses is much more significant than daily milk or even ME305 milk and helps us partition out variance not associated with the variables of interest.

The lactation data of 1,244 heifers with completed lactations were analyzed using the TDM approach and statistically analyzed several factors related to early life performance and the TDM milk yield residuals (Soberon et al. 2011). The factors analyzed were birth weight, weaning weight, height at weaning, BW at 4 weeks of age and several other related and farm measurable factors. From a management perspective the most interesting observation was the relationship among two factors, growth rate prior to weaning and intake over maintenance with first lactation milk yield. In these analyses, the strongest relationship associated with first lactation milk production was growth rate prior to weaning and the findings are consistent with the data presented in Table 4. In our data set, for every 1 pound of average daily gain (ADG) prior to weaning (or at least 42 to 49 days of age), the heifers produced approximately 850 pounds more milk ($P < 0.01$). The range in pre-weaning growth rates among the 1,244 animals were 0.52 to 2.76 pounds per day and the range was actually quite puzzling to us. Our feeding program at the research farm is straightforward: 1.5% BW dry matter from day 2 to 7 and then 2% of BW dry matter from day 8 to 42 of a 28:15 or 28:20 milk replacer mixed at 15% solids. Free choice water is offered year around and starter is offered from day 8 onward. At that feeding rate, we are offering twice the industry standard amount and had assumed it was enough for overcoming the maintenance requirement and provide adequate nutrients for growth, even in the winter. However, when we analyzed the TDM residuals by temperature at birth, a very significant observation was made (Figure 1).

These data very much suggest that although the nutrient supply was meeting the maintenance requirements of the calves from a strict requirement calculation, the diet was still not providing enough nutrients above maintenance to optimize first lactation milk production. It is important to remember that the thermoneutral zone for calves is 68° to 82° F and that when the temperature drops below that level, intake energy will be used to generate heat instead of growth. In addition, when the data were analyzed by lactation, the response increased as the animals matured (Table 2).

These data demonstrate there are metabolic programming events being affected in early life that have a lifetime impact on productivity. When we evaluated the 450 animals that had completed a third lactation, we found a lifetime milk effect of pre-weaning average daily gain of over 5,000 lb of milk depending on pre-weaning growth rates. Further, 22% of the variation in first lactation milk production could be explained by growth rate prior to weaning. This suggests that colostrum status and nutrient intake and or pre-weaning growth rate have a greater effect on lifetime milk yield and account for more variation and progress in milk yield associated with the management of the calf than genetic selection. Generally, milk yield will increase 150 to 300 lbs per lactation due to selection whereas the effect of management is three to five times that of genetic selection.

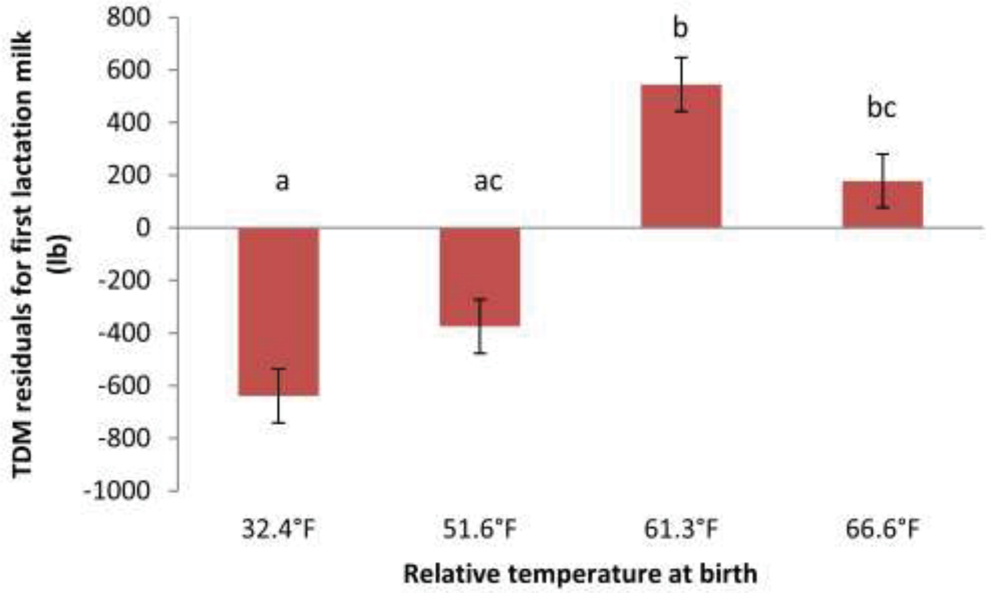

Figure 1. Test Day Model residuals in lb of milk, averaged by temperature at time of birth with mean temperature in Fahrenheit. Columns with different superscripts differ (*P* < 0.05).

Table 2. Predicted differences by TDM residual milk (lb) for 1st, 2nd, and 3rd lactation as well as cumulative milk from 1st through 3rd lactation as a function of pre-weaning average daily gain and energy intake over predicted maintenance for the Cornell herd.

Lactation	n	Predicted difference in milk per lb of pre-weaning ADG	P value	Predicted difference in milk (lb) for each additional Mcal intake energy above maintenance	P value
1st	1244	850	< 0.01	519	< 0.01
2nd	826	888	< 0.01	239	0.26
3rd	450	48	0.91	775	< 0.01
1st - 3nd	450	2,280	0.01	1,991	< 0.01

In the Cornell herd, the effect of diarrhea or antibiotic treatment on ADG was not significant and ADG differed by approximately 30 g/d for calves that had either event in their records (P > 0.1). However, for calves that had both events recorded, ADG was lower by approximately 50 g/d (P < 0.01). Over the eight year period, approximately 59% of all of the calves had at least one of the recorded events.

In the data from the Cornell herd, first lactation milk yield was not significantly affected by reported cases of diarrhea. Antibiotic treatment had a significant effect on TDM residual milk and calves that were treated with antibiotics produced 780 lb less milk in the first lactation ($P > 0.01$) than calves with no record of being treated. Regardless of antibiotic treatment, the effect of ADG on first lactation milk yield was significant in all calves ($P < 0.05$). Calves that were treated with antibiotics produced 622 lb more milk per lb of pre-weaning ADG while calves that did not receive antibiotics produced 1,406 lb more milk per lb of pre-weaning ADG (Soberon et al., 2011). The effect of increased nutrient intake from milk replacer was still apparent in the calves that were treated, but the lactation milk response was most likely attenuated due to factors associated with sickness responses and nutrient partitioning away from growth functions (Johnson, 1998; Dantzer, 2006).

An analysis of all the lactation data and the pre-weaning growth rates, when controlled for study, suggests that to achieve these milk yield responses from early life nutrition, calves must grow at a rate that would allow them to double their birth weight by weaning (56 days). This further suggests that milk or milk replacer intake must be greater than traditional programs for the first 3 to 4 weeks of life in order to achieve this response.

What changes in the animal are allowing for these differences? There is no one answer to that question but investigations are looking for several factors. Although mammary development as previously measured is probably not the appropriate factor (Meyer et al., 2006a, 2006b), it is intriguing to look at very specific cells within the mammary gland. There are a couple sets of data that demonstrate increased mammary cell growth based on early life nutrient intake. Brown et al. (2005) observed a 32 to 47% increase in mammary DNA content of calves fed approximately 2 versus 1 pound of milk replacer powder per day through weaning. Just like the milk production increases discussed earlier, this mammary effect only occurred prior to weaning. In fact, this increase in mammary development was not observed once the calves were weaned, indicating the calf is more sensitive to level of nutrition prior to weaning and that the enhancement of mammary development cannot be “recovered” once we wean the animal.

Meyer et al. (2006a) observed a similar effect in mammary cell proliferation in calves fed in a similar manner. The calves on their study demonstrated a 40% increase in mammary cell proliferation when allowed to consume at least twice as much milk replacer as the control group before weaning (Meyer et al., 2006a). Sejrsen et al (2000) observed no negative effect on mammary development in calves allowed to consume close to ad libitum intakes. A more specific attempt to look at stem cell proliferation did not find increased stem cells in calves fed higher levels of nutrient intake (Daniels et al., 2008) and it was hypothesized that the stem cell proliferation might lead to greater secretory cells once the animal becomes pregnant.

A recent study conducted at Cornell University compared organ weights of calves fed either restricted amount of milk replacer vs calves consuming double the amount of milk replacer. Calves that consumed more milk replacer pre-weaning weighed 48.5 lb more than restricted calves at weaning (1.4 times). The mammary gland of the calves on the high intake diet weighed 4.5 times more than the mammary gland of restricted calves while the epithelium in the mammary gland (fat free tissue) of the higher level intake calves weighed 5.9 times more than the epithelium of restricted calves (Soberon and Van Amburgh, 2011b). These findings are consistent and suggest that the mammary gland of cattle is nutrient responsive during at least the first five weeks of life.

ECONOMICS

An in depth economic analyses of a program designed to double the birth weight and decrease age at first calving by almost 3 months was conducted by Dr. Mike Overton with input from Dr. Bob Corbett (Overton, 2010). In his analyses he utilized both research and herd data to characterize the costs and potential income associated with feeding and managing calves in a manner to promote a milk yield response. In his analysis, the first lactation profit was $190 per heifer without accounting for the increase in inventory and what that means to changes in either voluntary culling or heifer sales. The change in profitability was due to the average 1,700 lb milk response observed from the studies described in Table 1 and was adjusted for net present value of the investment today relative to the income two years from now.

We conducted our own analysis of the response using calf and heifer performance data from a herd used in a heifer cost benchmarking study from New York (Table 3). There are many terms for the difference in management of the calves – in this analyses we will call it intensified but it really represents more biologically normal growth. Actual health data, feed costs and total costs of rearing were included in the estimation. Age at first calving was a function of getting heifers pregnant at 55% of the mature body weight and then calving at a minimum of 82% in both systems. In our analyses, AFC was reduced by 2.3 months, but the costs associated with achieving the same body weight post calving were nearly identical due to the higher costs of feeds and the amount of feed consumed to achieve the earlier AFC.

While the cost per heifer completing the system did not change, there are several other areas where there is economic value associated with the decreased calving age and the decrease in non-performance expense. If at the start there are the same numbers of heifer calves each month, there will be on average 2% more animals completing the system each year. There is also a decrease in the total number of animals in the replacement program, dropping 8%. This could allow the dairy to grow larger with the same replacement system, or allow the dairy to invest in a replacement program that was 8% smaller than before. The third area to impact profitability is the increased performance of the heifer in the dairy herd.
Using a model that treats the replacement program as a separate enterprise within the dairy, we looked at the combined changes for this herd, decreasing the calving age to 22.2 months, decreasing the non-performance rate to 7.5%, and fully transferring the increased value of production in the lactating herd. The non-completion rate was reduced due to a reduction in death loss with greater nutrient intake prior to weaning with no changes post-weaning, indicating there will be more heifers available to enter lactation. The base replacement enterprise was generating a return of 0.87% on assets

invested in the replacement program. With all the changes, the return increased to 7.2%.

Table 3. Cost assessment of conventional versus intensified calf and heifer programs

	Conventional	Intensified
Pre-weaning cost per pound gain, $	2.73	2.91
Total pre-weaning gain, lb	64	102
Age at pregnancy, mo.	15.4	12.2
Age at first calving, mo	24.5	22.2
Overall average daily gain from birth, lb	1.70	1.89
Body weight at calving, lb	1,350	1,350
Percent non-completion rate, % entering replacement program	10.2	7.5
Total cost per heifer, $	1,738	1,740
Total investment per heifer, $	1,887	1,890

The profitability increase is due to the potential decrease in inventory due to calving approximately 3 months earlier and the milk yield increase due to improved nutrition and management from birth. The management decisions associated with the inventory change due to AFC are difficult to generalize among all herds and it is really a one-time adjustment to the cost of production. However, given the potential change in milk yield over the life-time of the animal, the change in calf management in a program that maintains the targets throughout the growing phase is worth approximately $211, assuming a discount of 7% per year over the three year period, a $15 milk price, an income over feed costs of $10.50. This value is similar to the profit calculation of Overton (2010) and an outcome of the average milk response we are using to make the estimation along with the individual assumptions about costs of management.

Table 4. Replacement enterprise impact for selected management changes for a 250 cow herd. These values represent the differences in expenses associated with the heifer rearing enterprise associated with the calf raising program.

	Base	Lower Calving Age	Lower Non-Completion Rate	Combined Changes
Heifers to cows ratio, %	76	68	74	69
Total rearing costs, $	1,736	1,739	1,701	1,724
Income per animal, $	1,900	1,900	1,900	2,104
Completing system total investment, $	223,142	202,348	217,508	211,692
% Return on Capital	0.87%	0.53%	1.75%	7.27%

SUMMARY

Early life events appear to have long-term effects on the performance of the calf. Our management approaches and systems need to recognize these effects and capitalize on them. We have much to learn about the consistency of the response and the mechanisms that are being affected. Given the amount of variation accounted for in first and subsequent lactation milk yield, there is opportunity to enhance the response once we know and understand those factors. The bottom line is there is a positive economic outcome to improving the management of our calf and heifer programs starting at birth.

REFERENCES

Ballard, C., H. Wolford, T. Sato, K., Uchida, M. Suekawa, Y. Yabuuchi, and K. Kobayashi. 2005. The effect of feeding three milk replacer regimens preweaning on first lactation performance of Holstein cattle. J. Dairy Sci. 88:22 (abstr.)

Bar-Peled, U., B. Robinzon, E. Maltz, H. Tagari, Y. Folman, I. Bruckental, H. Voet, H. Gacitua, and A. R. Lehrer. 1997. Increased weight gain and effects on production parameters of Holstein heifers that were allowed to suckle. J. Dairy Sci. 80:2523-2528.

Brown, E. G., M. J. VandeHaar, K. M. Daniels, J. S. Liesman, L. T. Chapin, J. W. Forrest, R. M. Akers, R. E. Pearson, and M. S. Weber Nielsen. 2005. Effect of increasing energy and protein intake on mammary development in heifer calves J. Dairy Sci. 88: 595-603.

Daniels, K. M., A. V. Capuco, R. E. James, M. L. McGilliard, and R. M. Akers. 2008. Diet does not affect putative stem cells in pre-weaned Holstein heifers. J. Dairy Sci. 91 (E-Suppl. 1): 121 (Abstr.)

Dantzer, R. 2006. Cytokine, sickness behavior, and depression. Neurol Clin. 24:441-460.

de Paula Vieira, A., V. Guesdon. A. M. de Passille, M. A von Keyserlingk and D. M. Weary. 2008. Behavioral indicators of hunger in dairy calves. Applied Anim. Behavior Sci. 109:180-189.

DeNise, S. K., J. D. Robison, G. H. Stott and D. V. Armstrong. 1989. Effects of passive immunity on subsequent production in dairy heifers. J. Dairy Sci. 72:552-554.

Donovan, G.A., I. R. Dohoo, D. M. Montgomery and F.L. Bennett. 1998. Associations between passive immunity and morbidity and mortality in dairy heifers in Florida, USA. Prev. Vet.Med. 34:31-46

Drackley, J. K. 2005. Early growth effects on subsequent health and performance of dairy heifers. Chapter 12 in “Calf and heifer rearing: Principles of rearing the modern dairy heifer from calf to calving”. Nottingham Univ. Press. P.C. Garnsworthy, ed. Pp. 213-235.

Drackley, J.K., B. C. Pollard, H. M. Dann and J. A. Stamey. 2007. First lactation milk production for cows fed control or intensified milk replacer programs as calves. J. Dairy Sci. 90:614. (Abstr.)

Everett, R. W., and F. Schmitz. 1994. Dairy genetics in 1994 and beyond. Cow and sire evaluation using test-day records, DairyGene, and DairyView for farm management. Pages 4–39 *in* Mimeo Ser. No. 170, Cornell Coop. Ext., Cornell Univ., Ithaca, NY.

Faber, S. N., N. E. Faber, T. C. McCauley, and R. L. Ax. 2005. Case Study: Effects of colostrum ingestion on lactational performance. Prof. Anim. Scientist 21:420-425.

Foldager, J. and C.C. Krohn. 1994. Heifer calves reared on very high or normal levels of whole milk from birth to 6-8 weeks of age and their subsequent milk production. Proc. Soc. Nutr. Physiol. 3. (Abstr.)

Foldager, J., C.C. Krohn and Lisbeth Morgensen. 1997. Level of milk for female calves affects their milk production in first lactation. Proc. European Assoc. Animal Prod. 48th Annual Meeting. (Abstr.)

Furman-Fratczak K., A. Rzasa, T. Stefaniak. 2011. The influence of colostral immunoglobulin concentration in heifer calves' serum on their health and growth. J. Dairy Sci. 94:5536-5543.

Godden, S. 2008. Colostrum management for dairy calves. Vet. Clin. Food Anim. 24:19-39.

James, R. E., C. E. Polan, and K. A. Cummins. 1981. Influence of administered indigenous microorganisms on uptake of [Iodine-125] γ-Globulin in vivo by intestinal segments of neonatal calves. J Dairy Sci. 64: 52-61.

Jasper, J. and D. M. Weary. 2002. Effects of ad libitum milk intake on dairy calves. J. Dairy Sci. 85:3054-3058.

Johnson, R.W. 1998. Immune and endocrine regulation of food intake in sick animals. Domest Anim Endo. 15:309–319.

Meyer, M. J., A. V. Capuco, D. A. Ross, L. M. Lintault, and M. E. Van Amburgh. 2006a. Developmental and nutritional regulation of the prepubertal heifer mammary gland: I. Parenchyma and fat pad mass and composition. J Dairy Sci. 89: 4289-4297.

Meyer, M. J., A. V. Capuco, D. A. Ross, L. M. Lintault, and M. E. Van Amburgh. 2006b. Developmental and nutritional regulation of the prepubertal bovine mammary gland: II. epithelial cell proliferation, parenchymal accretion rate, and allometric growth. J. Dairy Sci. 89:4298–4304

Moallem, U., D. Werner, H. Lehrer, M. Kachut, L. Livshitz, S. Yakoby and A. Shamay. 2010. Long-term effects of feeding ad-libitum whole milk prior to weaning and prepubertal protein supplementation on skeletal growth rate and first-lactation milk production. J. Dairy Sci. 93:2639-2650.

Morrison, S. J., H.C.F. Wicks, R. J. Fallon, J. Twigge, L.E.R. Dawson, A.R.G. Wylie, and A. F. Carson. 2009. Effects of feeding level and protein content of milk replacer on the performance of dairy herd replacements. Animal. 11:1570-1579.

Mowrey, C.M. 2001. Influence of Feeding Pooled Colostrum or Colostrum Replacement on IgGL evels and Evaluation of Animal Plasma as a Milk Replacer Protein Source. S. S. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Nocek, J. E., D. G. Braund, and R. G Warner. 1984. Influence of neonatal colostrum administration, immunoglobulin, and continued feeding of colostrum on calf gain, health and serum protein. J. Dairy Sci. 67:319-333.

Overton, M. 2010. Economic comparison of conventional vs. intensive heifer rearing systems. American Association of Bovine Practitioners Pre-Conference Seminar 10, Albuquerque, NM.

Raeth-Knight, M., H. Chester-Jones, S. Hayes, J. Linn, R. Larson, D. Ziegler, B. Ziegler and N. Broadwater. 2009. Impact of conventional or intensive milk replacer

programs on Holstein heifer performance through six months of age and during first lactation. J Dairy Sci. 92:799-809.
Rincker L. E. D., M. J. VandeHaar, C. A. Wolf, J. S. Liesman, L. T. Chapin, and M. S. Weber Nielson. 2011. Effects of intensified feeding of heifer calves on groth, pubertal age, calving age, milk yield, and economics. J. Dairy Sci. 94:3554-3567.
Robison, J. D., G. H. Stott and S. K. DeNise. 1988. Effects of passive immunity on growth and survival in the dairy heifer. J. Dairy Sci. 71:1283-1287.
Sejrsen, K., S. Purup, M. Vestergaard, and J. Fodager. 2000. High body weight gain and reduced bovine mammary growth: physiological basis and implications for milk yield. Domes. Anim. Endo. 19:93-104.
Shamay A., D. Werner, U. Moallem, H. Barash, I. Bruckental. 2005. Effect of nursing management and skeletal size at weaning on puberty, skeletal growth rate, and milk production during first lactation of dairy heifers. J. Dairy Sci. 88:1460-1469.
Soberon F., and M. E. Van Amburgh. 2011a. Effects of colostrum intake and pre-weaning nutrient intake on post-weaning feed efficiency and voluntary feed intake. J. Dairy Sci. 94:69-70 (Abstr.).
Soberon F., and M. E. Van Amburgh. 2011b. Effects of pre-weaning nutrient intake in the developing mammary parenchymal tissue and fat pad. J. Dairy Sci. 94:73 (Abstr.).
Soberon, F., E. Raffrenato, R. W. Everett, M. E. Van Amburgh. 2011. Pre-weaning milk replacer intake and effects on long term productivity of Dairy calves. J. Dairy Sci. (Accepted for publication).
Van Amburgh, M. E., D. M. Galton, D. E. Bauman, and R. W. Everett. 1997. Management and economics of extended calving intervals with use of bovine somatotropin. Livest. Prod. Sci. 50:15–28.